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HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

REVIEW OF LITERATURE ON CONDITIONING AIR FOR ADVANCEMENT OF HEALTH AND SAFETY IN MINES

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BY

D. HARRINGTON AND SARA J. DAVENPORT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON CONDITIONING AIR FOR ADVANCEMENT OF HEALTH AND SAFETY IN MINES[1]

PART I

By D. Harrington[2] and Sara J. Davenport[3]

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INTRODUCTION

This circular presents part I of a series of papers of a review of the literature on air conditioning in mines, with particular reference to the health, safety, and efficiency of mines. It deals with the physiological aspects of exposure to air contaminated by organic matter, noxious and toxic gases, and dusts that emanate from various sources in underground workings; part II will discuss the relation of abnormal mine temperatures and humidities to the health and efficiency of miners; and part III will describe theoretical and practical methods of air conditioning mines to correct or alleviate the conditions mentioned and will discuss the results attained by some of the systems now in use in various parts of the world.

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[1] The Bureau of Mines will welcome reprinting of this information circular, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7001."

[2] Chief, Health and Safety Branch, Bureau of Mines.

[3] Principal translator, Bureau of Mines.

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The importance of the atmosphere to which human beings are exposed to their physical and mental health is so much under discussion at present as to lead to the assumption that knowledge of its physiological effects is comparatively recent. However, Petersen (1)[4] has called attention to the emphasis placed on the importance of meteorological conditions to health and disease by Hippocrates (460-359 B.C.) who said:

> For with the seasons, men's diseases, like their digestive organs, suffer change.

The Greeks claimed to have derived the healing arts through Apollo, the air god, and Hippocrates (1) argued that all disease is due fundamentally to interference with the supply of air (oxygen) to the tissues (a generalized or regional anoxemia).

Mining always has been considered a more or less dangerous and unhealthy occupation. Although persons are still killed by toxic and noxious air in mines from explosions, fires, lack of respirable air, dusts, and excessive heat, present conditions have improved immeasurably beyond those that prevailed during the early days when mining was done by slaves, and men, women, and children "worked in small holes, damp and dark, and foul for lack of ventilation" (2).

Ventilation and air conditioning are closely related but slightly different phases of the problem of making mine air healthy and safe for mine workers. According to Webster's Dictionary "to ventilate is to cause fresh air to circulate through (to replace foul air simultaneously removed) a room or mine." Ventilation also has been defined (3) as "the process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned." Ventilation of underground workings comprises establishment of such control of air currents that underground workers may work in safety, with maximum comfort and efficiency and without impairment of health; that the air flow in mine openings may be made subject to such control as to remove harmful gases and dusts from the workings at ordinary times; and that in an emergency, such as fire or explosion, as much or as little air flow may be maintained as desired in parts of the mine or the mine in its entirety (4).

Although quantity rather than quality of air supplied usually is implied by "ventilation", the term is coming more and more to include the idea of quality from the standpoint of health and comfort of those exposed thereto. In States where ventilation in mines is regulated by law, the basis of calculation is the quantity of air to be supplied per person and per animal underground. Requirements range from an indefinite "operator must furnish good ventilation" or "sufficient current of fresh air for health and safety of miners" in some States to a more or less definite "not less than 85 cubic feet per minute per person and 500 per animal" and "150 cubic feet per minute per person and 600 per animal in gassy mines" in other States. The average requirement is 100 cubic feet per minute per person and 500 per animal. Apparently most State laws contain no restrictions regarding the quality of the air supplied.

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[4] Numbers in parentheses refer to bibliography at end of circular.

"Air conditioning" in its broadest sense includes ventilation and implies control of any or all of the physical or chemical qualities of the air, such as temperature, humidity, movement, distribution, dust, bacteria, odors, toxic gases, and ionization - all of which affect human health, comfort, and working efficiency to some extent (3). This series of papers deals with the subject as applied to mining.

NEED FOR AIR CONDITIONING

Chapter 1. General Foulness of Underground Air

Up to the present, ventilation has been supplied to underground workings mainly to dilute toxic gases and dust and to prevent accumulations of explosive gas mixtures, with occasional attempts to minimize the ill effects of high temperatures and humidities. Consideration of air conditioning in mines has been confined almost exclusively to heat and humidity, with some implication of helping to reduce air dustiness, and the bad effect on the workers of mine atmospheres in certain places usually is attributed to excessive wet-bulb temperatures; to most people air conditioning means cooling the air in enclosed places in hot weather. In addition to temperature and humidity there are, however, other factors, such as general foulness of the air due to the putrefaction of decaying organic matter, emanations from the lungs and bodies of workers and animals, and the presence in the air of small quantities of toxic or noxious gases or possibly of large or small amounts of dusts. Referring to the less commonly discussed causes of ill health among miners in a talk before the Chemical, Metallurgical, and Mining Society of South Africa, Joseph (5) stated that, although excessive wet-bulb temperature seriously impairs human vitality, the additional ill effects caused by foul impurity of the air are much more serious and the ultimate toxic effect cannot be disregarded, whatever the degree of disability, as it is certain to be cumulative. As an instance of what can happen in extreme cases he cited ptomaine poisoning as a result of working continuously in an atmosphere foul from decaying organic matter. He tabulates the causes contributing to the ill effects of mine air in the following order of importance:

	Percent
1. Wet-bulb temperature	50
2. Fouling of the atmosphere and consequent "stink"	25
3. Effect on body metabolism and breathing mechanism	10
4. Direct action on the nervous system	10
5. Psychological effect of working underground and in such an atmosphere	5
Total	100

Discussion of Joseph's statement revealed that his percentages for the factors other than heat and humidity were too high and that most mining men would consider that high wet-bulb temperature and humidity account for more than 50 percent of the air-condition difficulties in deep mining. It was also suggested that items 1 and 2 of the table were causes, 3 and 4 effects, and 5 a combination of causes and effects. On a somewhat broader basis the following were presented as the principal causes of lowered efficiency:

1. Low cooling power, or high effective temperature.
2. Contamination of the air from organic sources.
3. General underground environment.

These contribute in various degrees to the effects indicated in items 3, 4, and 5 of Joseph's tabulation. In other words, these causes were suggested as producing certain physiological and psychological effects which combine to lower the physical and mental efficiency of underground workers. Physiologists and psychologists should be able to do better than guess at the relative importance of these causes in lowering efficiency. It is interesting to note here that in 1909 Young (6), in discussing results of an investigation of the effects of high temperatures and humidities on workers in the deep workings of the Virginia City (Nev.) mines, remarked that "vitiated air will impair labor efficiency to a greater extent than a high temperature."

Discovery by Black (7) in 1757 that expired air contained carbon dioxide in which animals died of suffocation and by Lavoisier (8) in 1777 that the oxygen of the air when taken into the body combined with carbon to form carbon dioxide led to the generally prevailing belief that the ill effects experienced by people crowded in small, enclosed, and poorly ventilated spaces are due to lack of oxygen and accumulation of carbon dioxide. Pettenkofer (9), however, questioned the carbon dioxide theory in 1862 by calling attention to the fact that the air of a room filled with human beings is disagreeable and offensive and appears foul and nauseous long before it is too greatly deprived of oxygen or laden with more than 1 percent of carbon dioxide. Further investigations seemed to indicate that the ill effects in atmospheres in surface structures were due not so much to the chemical impurities in the air as to its physical properties (temperature, humidity, and motion) and that the objection to an evil-smelling atmosphere was based not on its poisonous properties, which had never been proved to exist, but on the nausea, loss of appetite, and general malaise that followed the prolonged breathing of a large quantity of volatile malodorous products (10).

Kitchin (11) believed that the presence of volatile organic poisons emanating from bodily activities may have not only undesirable and depressing but also irritating influences. He said:

> If the individual's own body suffers from autogenerated toxic matters originating in the alimentary tract and diffused through the body, why should not a fellow human being suffer from the effects of some of those same materials escaping from the body in the expired air and from the cutaneous surfaces.***

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> It is certain that various excretory volatile matters from the human body produce nausea, loss of appetite, and other disturbances, and if that result is commonly to be observed we have no right to say that there are not injurious matters in poor air other than heat, moisture, and lack of movement.

The belief that the products of respiration are nontoxic apparently has been challenged by later experiments. In 1933 Schroeder (12) published results of experiments which seem to indicate that such products are highly poisonous. He found that, in addition to moisture and carbon dioxide, a number of substances of complicated chemical structure, made up of various complex organic compounds, are included in the products of respiration. The digestive juices and food are subject to the decomposing action of bacteria found in the digestive tract and particularly in the large intestine. As a result of this decomposition a large number of more or less toxic compounds are formed from the protein material in the intestines. Some of these products he identifies as fusel oil, fatty acids, aromatic acids, methane, hydrogen sulphide, amino-acids, cresol, indole, and skatole, and he believes that a very small proportion of these products in the air causes a stuffy, crowded feeling, due to their high toxicity. In experiments on rats the organic material obtained from three rats was toxic to a fourth. An interesting fact noted by Schroeder was that the breath of one of his subjects, a man who very probably had tuberculosis, had a very high carbon dioxide and also a high organic-material content. He suggested that it might be interesting to analyze the breath of a large number of tubercular patients to determine whether high content of carbon dioxide and organic material is a characteristic of the disease. The breath of old or diseased persons is said to be more toxic than that of healthy young persons (13).

It has been determined experimentally (14) that the sense of smell normally is aroused by inconceivably small concentrations of odoriferous substances, sensitivity varying in different individuals. In a review on odors and odor control, Pierce (15) reported that 0.0000005 milligram of oil of rose per cubic centimeter of air can be smelled distinctly. Mercaptan, a liquid with a penetrating garlic odor, can be smelled in much smaller concentrations, and this fact is utilized in warning miners of untoward occurrences through the compressed-air system or in calling attention to leakage in city gas systems. The odor of butyric acid, a constituent of the body-odor complex, can be detected in concentrations of 0.000009 milligram per cubic centimeter of air. The investigation (14) also revealed that the olfactory organs are fatigued quickly and easily if the exciting stimulus continues, although the sudden appearance of new odors can be perceived. Recovery of excitability is apparently rapid, and breathing fresh air for 5 to 10 minutes restores full excitability to body odors after exposure of 3 to 4 hours in crowded and poorly ventilated rooms. Healthy and clean persons, even immediately after a bath, give off an appreciable odor, which apparently is a normal waste product arising from metabolic processes and decomposition of matter in the skin and clothing. Such odors in a room are not considered harmful, but the occupants, even when unconscious of the odor, seem to be capable of detecting stuffi-

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ness or lack of freshness in the air, and sensitive persons are occasionally affected pathologically by remaining in such rooms. Apparently it is not known definitely whether exposure to such air conditions is harmful to health, but from some of the symptoms mentioned they may prove harmful, at least after long exposure, and investigators seem to agree that such conditions should be controlled preferably by personal habits of cleanliness, by ventilation and air conditioning, or by both.

Where men are performing hard physical labor under ordinary mining conditions and where there may be more or less subconscious psychological sensitiveness to the lack of freshness of the air due to the presence of men and animals, personal cleanliness is hardly a feasible method of control; ventilation, air conditioning, or both would be required to remove the foul air, especially where temperature and humidity are above normal.

In addition to the little-considered sources of air contamination underground already discussed there are, of course, the more obvious and generally known health-affecting conditions that result from the presence of gases, dusts, and abnormal temperatures and humidities, all of which can and should be controlled by effective ventilation or air conditioning. The causes, physiological effects, and methods of control of these health- and efficiency-destroying conditions will be discussed in this paper and others to follow.

Chapter 2. Gases Encountered in Mines

Pure, dry air at sea level contains the following gases (16):

Gas:	Percent
Oxygen (O_2)	20.94
Nitrogen (N_2)	78.09
Carbon dioxide (CO_2)	.03
Argon (A)	.94
Helium (He), neon (Ne), krypton (Kr), xenon (Xe), hydrogen (H_2), hydrogen peroxide (H_2O_2), ammonia (NH_3), and ozone (O_3)	Trace

The rare gases are inert and usually are included with nitrogen. In addition to the gases mentioned, inhaled air is accompanied by approximately 1 percent of moisture and exhaled air by approximately 5 percent of moisture. So exactly are these conditions adjusted to the requirements of normally healthy subjects that the body is affected by slight changes in the constituents of the inhaled air. A slight reduction of oxygen to 20.19 percent and an increase of carbon dioxide to 3.84 percent are said to cause severe headache within a very few minutes (17), and this is especially true where the temperature and humidity are high.

Mixed Gases

The air of mines is likely to be contaminated by various gases, known by many miners (especially "old-timers") as black or choke damp, firedamp, afterdamp, and white damp, as well as by smoke and dust. Oxides of nitrogen, sulphur dioxide, and hydrogen sulphide (stink damp) also may be present under certain conditions, usually in small amounts, although they may be present in high enough concentration to be dangerous.

Blackdamp. - Blackdamp is the gas most universally present, and large quantities are present in many poorly ventilated mines; it consists usually of carbon dioxide, nitrogen, and oxygen in varying (for the most part deficient) quantities. In the pure state it consists of 85 to 99 percent nitrogen and 1 to 15 percent carbon dioxide (18). According to Haldane (19) "it is the residual gas of an oxidation process and thus consists of nitrogen with anything up to about 21 percent of carbon dioxide." The most important source of blackdamp in mines is the oxidation of timber, coal, and iron pyrites or the decomposition of minerals especially those with carbonate base. Blackdamp of varying composition is found in virtually all mines and is distinguished by miners through its characteristic property of extinguishing lamps without exploding.

The physiological action of blackdamp in air depends, within wide limits, on the percentage of carbon dioxide in the blackdamp, although of course the oxygen content is also highly important. The effects of breathing blackdamp are those of oxygen deficiency and are described later under the discussion of the effects of oxygen want. Haldane (19) mentions that the presence of carbon dioxide diminishes greatly the risk that would otherwise exist from the diminution of oxygen percentage, owing to the fact that CO_2 increases the oxygen percentage in the alveolar air by stimulating breathing and raises the hydrogen-ion concentration (increases the acidity) of the blood, thus increasing the circulation rate and assisting the dissociation of oxyhemoglobin in the tissue capillaries. There is, therefore, little or no danger from lack of oxygen until the oxygen percentage in the air falls to 6 or 7 percent; if the oxygen falls much lower death occurs from oxygen want.

Firedamp. - Firedamp is a combustible gas composed principally of methane, but it also may contain small proportions of hydrogen, ethane, and higher hydrocarbons. It always occurs mixed with various amounts of oxygen, nitrogen, and carbon dioxide (18). There is always the risk in mining, and especially in coal mining, of drilling into a pocket of methane and possibly, in isolated instances, of hydrogen. This is by no means rare and may be attended by fatal results. Pure methane is colorless, odorless, and tasteless. In certain concentrations it burns in air or oxygen with a pale-blue flame. It contains no oxygen, is not a supporter of combustion in the generally accepted meaning, and unmixed with air quickly extinguishes a lamp flame; however, mixed with air in certain proportions - approximate limits of inflammability in air, 5.3 to 14 percent by volume (20) - it is explosive (21). Although methane is nontoxic it may so dilute the oxygen of the air as to produce the anoxia described in the discussion of oxygen, and this is a definite hazard in some mining places.

There has been some discussion as to whether the effects of inhaling air containing methane are due entirely to anoxia - disturbance in the oxygen supply and utilization in the body (22) - or whether the gas is poisonous. The following statement from Glaister and Logan's Gas Poisoning in Mining and Other Industries (23) indicates that methane has no effect other than oxygen want:

> Methane has no poisonous action on man, and one might breathe with impunity an atmosphere containing a large percentage of methane, provided the atmosphere contains a sufficient amount of oxygen. So long as the amount of oxygen is not seriously reduced, no ill effects can result from the breathing of firedamp. As Paul Bert pointed out long ago, the physiological effects of firedamp are just like those produced by air from which a proportion of its oxygen has been removed. Contrary to the general opinion, however, that firedamp produces no effects unless CO or CO_2 is present, or where the percentage of oxygen is much lowered, Lussem (24) has demonstrated by experiments that where a large percentage of CH_4, is present a stupefying effect is produced. For example, he found that when animals breathed a large quantity they became very sleepy, while on men also it has a stupefying effect. But in all cases recovery was very rapid when the patient was placed in fresh air. Experimenting with olefiant gas, he found that this action was much more pronounced, as it had a distinct narcotic effect on man.
>
> It is well to remember, however, that the very presence of these different gases in the air means a reduction in the amount of oxygen present, and also that wherever there is much methane, it necessarily follows that there is also present an increased amount of CO_2. In itself then, marsh gas has no toxic action on man except in the absence of sufficient oxygen, when it may lead to asphyxiation.

Henderson and Haggard (25) list methane as a simple asphyxiant and stat that simple asphyxiants are of two types - those entirely inert physiologically and those with "some slight, specific action." When members of the latter group "are inhaled in high concentration with air they cause asphyxi before this action is manifest." The latter group includes "the lighter hydrocarbons of the aliphatic series, such as methane and ethane, and some the gases which, when administered with oxygen, are now used as anesthetics. These authors state that the simple asphyxiants act entirely by excluding oxygen from the lungs; their effect is proportional to the extent to which their presence diminishes the percentage, or rather pressure, of oxygen in the inspired air. They all act identically, therefore, when present in equal molecular concentration. Moreover they must be present in considerabl amounts before they exert an appreciable effect. In the sections describing the symptoms of anoxemia the authors (25) stated that the oxygen can be reduced to two-thirds of its normal percentage in the air before noticeable symptoms of anoxemia develop. A reduction of the oxygen to this degree necessitates the presence of the simple asphyxiants in a concentration of 33 percent in the mixture of air and gas. When 50 percent of the gas is present a man is soon rendered incapable of making a vigorous effort to escape. About 75 percent is quickly fatal.

After examining many persons whose lives had been spent in firedamp-laden mines and persons who had been asphyxiated by firedamp, Hautain (26) concluded that asphyxia by methane is due entirely to lack of oxygen. This was confirmed by experiments in the laboratory of the National Institute of Mines of Belgium as follows:

> Guinea pigs, mice, little birds, a dog weighing 12 lb., and one weighing 29 lb. were used in these tests, which were made with Belgian mine gas in concentrations of not more than 36 percent methane, then with coke-oven gas carefully freed of hydrogen and carbon monoxide and analyzing 70 to 72 percent methane, and lastly with Saar firedamp containing 92 percent of methane. For comparison, experiments were made also with nitrogen and hydrogen - inert gases.
>
> Despite the facts advanced by Dr. Hautain in support of his belief, the investigators concluded that methane is inert and not poisonous. The experiments showed, however, what a small oxygen content sufficed to sustain life in the bodies of animals. The smaller dog rested for 8 hours without any discomfort in a glass enclosure, breathing gas from the Paturages gasometer which had 8 percent of oxygen, 36.6 of methane, 54.76 of nitrogen, and 0.64 of carbon dioxide.
>
> One is astonished, says Professor Breyre, the administrator general of the institute, that animals can continue to live in such high percentages of inert gas when one recalls with what rapidity men fall in methane mixtures, notably in face workings without a return airway, but, under such circumstances, he adds, the methane is concentrated and does not readily diffuse itself into the surrounding air.

Afterdamp. - Afterdamp is a mixture of air, blackdamp, white damp (carbon monoxide), and carbon dioxide. It results from mine fires and from the explosion of firedamp or coal dust, or both, and air and when fresh sometimes is deeply colored by smoke or soot (18). Haldane states (19) that an inquiry into the causes of death in colliery explosions revealed that about 95 percent of the men who died underground were killed by carbon monoxide, although a considerable number had received such serious skin burns that they hardly could have survived in any case; death was never due to deficiency of oxygen in the air, excess of carbon dioxide, or, apart from exceptional cases, to more than 2 percent of carbon monoxide; it was clear that the men had died in air containing plenty of oxygen and not much carbon monoxide. This statement might be contradicted, or at least modified, by persons familiar with conditions in mines of the United States after mine explosions.

Smoke from blasting may contain various poisonous gases, as well as CO_2, according to the nature of the explosive used. All explosives apparently give off some CO, and some are likely to give off oxides of nitrogen as well as other toxic gases. Black blasting powder produces both CO and H_2S; in cases of gassing it is often difficult to decide which gas has been responsible (19). When explosives containing nitrogen burn instead of detonating, the nitrogen forms oxides of nitrogen along with CO instead of CO_2.

The effects of breathing air containing different concentrations of oxygen, carbon dioxide, oxides of nitrogen, hydrogen sulphide, and sulphur dioxide are described in the following sections devoted to each gas.

Oxygen

Air is the most important of the vital requirements in the environment of living things, and oxygen probably is the most necessary constituent of the air. Although too much oxygen in the air is not harmful like oxygen deficiency, it may under some circumstances have ill and even disastrous effects if breathed by a healthy individual in excess of his needs (27) or at higher than normal atmospheric pressures.

According to Webster's unabridged dictionary oxygen is a colorless, tasteless, odorless, chemically active, gaseous element occurring in the free state in the atmosphere and combining with all the elements except argon and fluorine; the process of combination is called oxidation, of which ordinary combustion is a more intense form. Oxygen is a little heavier than air; a liter of normal air (760 mm and 0° C.) weighs 1.292 grams, while a liter of oxygen (760 mm and 0° C.) weighs 1.429 grams. Oxygen is soluble in water; 100 volumes of water at 0° C. can dissolve nearly 5 volumes of oxygen under normal pressure and at 20° C., 3 volumes of the gas (28).

Effects of breathing high concentrations of oxygen. - The normal pressure of oxygen in the air is 20 percent or 152 mm. Atmospheric air supplies an excess of air over the needs of the body, and under ordinary conditions of rest or moderate activity breathing pure oxygen has no beneficial effect. However, in performing heavy muscular work the muscles use more oxygen, and if the work is continued for some time the quantity of oxygen in the air may be insufficient in spite of the increase in respiration and circulation. In such cases an increase in the percentage of oxygen in the inspired air enables the muscles to contract more efficiently and to perform more work (29). According to Bert (30) the maximum effect of oxygen under these conditions is obtained when its pressure in the inspired air reaches 60 to 70 percent; however, he concludes from many experiments on animals and plants that all living things are killed at pressures of 300 to 400 percent.

Investigators seem to disagree as to the harmfulness of breathing high concentrations of pure oxygen. Oxygen pressures of 100 to 130 percent (1 to 1.3 atmospheres) are said by some (29) to kill animals in a few days and those of 180 percent (1.8 atmospheres) to kill mice and birds within 24 hours. Others (31) claim that rats, guinea pigs, and rabbits develop fatal pneumonia when exposed to 70 to 100 percent oxygen for 3 to 15 days, although experiments show that these animals can be exposed without apparent harmful effects

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to virtually 100 percent oxygen 16 hours a day for 50 consecutive days. Mules exposed to 60 percent oxygen for more than a year in the Hudson tunnels remained in perfect health (32). German investigators state (33) that the long-current belief that it is injurious to health to breathe pure oxygen for any length of time is in error, as investigations with gas protective apparatus such as oxygen mine rescue breathing-apparatus show that the oxygen content may be increased to 100 percent and that it is not dangerous to breathe air containing high concentrations of oxygen as long as the pressure is normal.

According to Evans (31) no harmful effects resulted from administering 60 to 100 percent oxygen continuously for several days to cyanotic patients. On the contrary, these high concentrations proved beneficial and apparently saved many lives. He found that administration of oxygen cleared up edema of the lungs when it was present instead of producing it; it would not have done this had oxygen been an irritant.

Sayers (34) has found that animals can live in pure oxygen for 16 hours a day without harmful effects. This was confirmed by Barach (34), but he discovered also that pulmonary edema developed when animals were kept the rest of the 24 hours in 50 percent oxygen instead of air. He believes, however, that it is safe to administer 90 to 100 percent oxygen for 10 to 12 hours a day and 50 percent the rest of the time.

Behnke (35) and his coworkers studied the mental and physical effects induced by breathing 96 to 99 percent oxygen at pressures of 1, 2, 3, and 4 atmospheres and concluded that healthy men between the ages of 22 and 40 can breathe pure oxygen with comparative safety as follows: 4 hours at 1 atmosphere; 3 hours at 2 atmospheres; and 2 hours at 3 atmospheres. At 4 atmospheres one subject had convulsions and another fainted after exposures of approximately 45 minutes (only two subjects were tested at this pressure). Exposure to 1 atmosphere for 1 to 3 hours caused impaired neuromuscular coordination and power of attention (or increased effort to maintain these functions) in 3 of 4 subjects tested, and exposure to oxygen for 3 hours caused moderate exaggeration of respiratory movements in 2 of 11 subjects. Oxygen consumption was found to be high during the first 20 minutes and then decreased to a constant level for periods up to 4 hours at atmospheric pressure. Blood pressure, respiratory rate, and minute volume[5] (with two exceptions) were constant at the four pressures.

Although the administration of oxygen may help to relieve symptoms accompanying increased muscular activity and thus make possible greater-than-normal activity, the capacity for physical exertion is modified by the capacity of the respiratory and circulatory apparatus to adjust themselves to augmented tasks (36). Respiration and circulation have been called the servants of the muscles, therefore, when the limit of ability to supply oxygen is approached or reached, compensation may fail due to the inadequacy of respiration and circulation. Schneider (37) has called attention to the close relationship of oxygen absorption, minute volume, respiratory rate, frequency of heart beat, oxygen pulse, and performance of muscular work.

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[5] Volume respired per minute.

Effects of breathing increased percentages of oxygen are of interest in mining, especially in connection with the wearing of oxygen breathing-apparatus, in caisson and tunnel work, and in the treatment of poisoning by toxic gases.

Effects of breathing air deficient in oxygen. - Breathing air deficient in oxygen is of course a much greater and more frequent hazard in mining than exposure to higher-than-normal concentrations of the gas. When normal air, which contains about 21 percent (20.94 percent) oxygen, is circulated through a mine it loses some of its oxygen by the breathing of men and animals, and a certain amount is absorbed by the coal and timber or combined chemically with minerals such as pyrite, marcasite, etc.; moreover, the oxygen content of the air may be diluted by intrusion of extraneous strata gases, such as nitrogen, carbon dioxide, methane, etc., or by gases formed by action of chemicals in mine water on minerals or rocks. The absorbed oxygen is replaced largely by carbon dioxide, which is given off by the breathing of men and animals, by the coal and decaying timbers, and by chemical action of water and rock (16); large or small quantities of methane (CH_4) may also replace some oxygen, the amount depending on the volume of the air current and the amount of methane that is being liberated. Most coal mines give off or are likely at any time to give off methane, and in some mines (especially metal mines) gases intrude from the strata - nitrogen, carbon dioxide, hydrogen sulphide, etc.

Peters and Van Slyke (22) use the term "anoxia" (meaning literally "oxygen lack") to cover any condition that retards the oxidation processes in the tissues; the less specific word "anoxia" seems preferable to the specific term "anoxemia" (meaning literally oxygen deficit in the blood) generally used in the literature. These investigators (22) classify anoxia according to types as follows:

1. Anoxic anoxia. If there is a deficit in the arterial oxygen tension at which the blood delivers oxygen to the cells the latter are compelled to work at a lower pressure.

2. Anemic anoxia. The same result follows if, because of lack or inactivation of hemoglobin, the volume percent of oxygen that can be carried by the arterial blood is low; in this case removal of the usual volume percent of oxygen from the blood by the cells is accomplished by an abnormally great fall in tension.

3. Stagnant anoxia. Even when the arterial blood has an entirely normal oxygen content and pressure, anoxia in the cells occurs if the circulation is so retarded that the oxygen is not transported rapidly enough to maintain its optimum tension in the active tissues.

4. Histotoxic anoxia. Furthermore, with oxygen supply perfectly normal in all respects, anoxia may nevertheless occur if the tissue cells are poisoned in such a manner that they cannot use the oxygen properly. This type, which we shall call histotoxic anoxia, occurs in poisoning by cyanide, alcohol, and apparently certain other narcotics.

To illustrate the different origins of the types of anoxia, the oxygen supply of the body and its tissue cells is compared to the milk supply of a house and its inmates; starvation may arise because: (1) The supply is too dilute to support life; (2) even with a perfect supply delivered at the door the servants (erythrocytes) may be too few; (3) they may be too sluggish in movement to transport it to the table as rapidly as needed; or (4) despite perfect material and transportation, the family (tissue cells) may be too intoxicated to consume what is set before them.

The effects of breathing air deficient in oxygen vary with the concentration of the gas or, in other words, with the amount or degree of the deficiency. According to Haldane (19), if pure anoxemia is produced suddenly, loss of consciousness occurs suddenly and without previous warning symptoms. A miner who puts his head into a cavity in the roof full of pure or nearly pure methane or nitrogen drops as though he had been felled, and when he recovers after breathing pure air for a few seconds he sometimes imagines that he has been knocked down by another man and acts accordingly. If the anoxemia results with moderate rapidity, marked temporary disturbances in breathing and circulation as a rule give some warning of what is coming. If the onset is gradual, little or no preliminary discomfort is experienced, therefore lack of oxygen is very dangerous not only in mine workings but especially in ascents to high altitudes in balloons and airplanes, as well as under other conditions in which it is a factor.

Symptoms of anoxic anoxia (due to breathing air of diminishing oxygen content) appear at different oxygen pressures in different individuals, depending upon health, physical fitness, age, etc. (29). Schneider (38) found that during rebreathing tests in the medical research laboratory of the Air Service, a few men experienced an increase in lung ventilation with the first decrease in the oxygen percentage of the air breathed, which increased gradually in inverse ratio to the reduction in oxygen. More than 50 percent of the men examined, however, gave the first respiratory response at 16 to 14 percent of oxygen; 25 percent responded first at a lower percentage; and a few gave no response. The response was slight in most subjects but became more pronounced when the available oxygen had decreased to 12.5 to 9 percent. With 8 to 6 percent oxygen most of the men breathed 5.5 liters more than at the beginning of the experiment, and depth of breathing increased 20 to 128 percent. When the minute volume of breathing failed to increase or increased only slightly (1 or 2 liters) as the amount of oxygen inhaled decreased, lung ventilation was insufficient, and the subject was unable to tolerate as low an oxygen tension as the man whose breathing gradually deepened as the available oxygen decreased (38).

According to Schneider (38), a very marked acceleration in heart beat occurs when the oxygen has fallen to 13 to 9 percent. Some men at first react with a good acceleration rate but soon reach a rate beyond which there is no further response, even though the oxygen percentage continues to be lowered; after holding this rate for a while the heart in such cases suddenly begins to slow, a sure sign that the limit of endurance has been reached. An acceleration in heart rate of more than 40 beats per minute throws too great a burden on the circulatory mechanism and indicates poor tolerance of low percentages of oxygen.

Hingston (39) reported the following reactions to oxygen deficiency among the men attempting to climb Mt. Everest in 1924:

Percent O_2	Feet	Effects
12.28	14,000	Definite shortness of breath.
10.56	18,000	Severe exercise caused quick and labored breathing.
9.41	21,000	Slightest exertion caused respiratory distress.
7.35 7.03	27,000 to 28,000	Breathing so difficult that rate of progress was incredibly slow (1 hour to climb 100 feet), and it was necessary to rest 1 to 2 minutes every 20 to 30 yards.

Cheyne-Stokes respiration (respiration varying in intensity) began frequently at 12,000 feet (13.23 percent of oxygen) during sleep and was marked in cases of illness. Headache was common but not severe; loss of muscular power, forgetfulness, and mental lassitude were experienced, but there was no impairment of judgment. Hingston stated that, contrary to the experience of the previous expedition, oxygen was of little value.

Hingston's statements that there "was no impairment of judgment" and that "oxygen was of little value" in connection with breathing oxygen-deficient air do not agree with statements of other investigators. According to Haldane (19) powers of sane judgment are much impaired, and a gradual and insensible failure of judgment is experienced; anoxemic persons become more or less subject to irrational fixed ideas and to uncontrolled emotional outbursts. Haldane states also that the symptoms of oxygen want resemble those of drunkenness and that a man suffering from anoxemia cannot be held responsible for his actions, although he is always confident that he himself is perfectly sane and reasonable and usually will insist in going on with what he has set out to do. An airman probably will continue to ascend, oblivious of danger; a miner engaged in rescue or exploration work or in fighting a mine fire, when he is suffering from lack of oxygen, often fights anyone who tries to make him stop.

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An interesting description of the reactions to oxygen deficiency of a pilot flying at high altitudes has been reported by the Bureau of Aeronautics of the Navy Department (40):

> When a pilot flying at high altitudes notices his fingers beginning to twitch, it is time for him to seek the safety of lower levels, it appears from the experience of a U. S. Navy pilot.
>
> The incident which showed twitching fingers to be a danger signal is reported by the Navy Department's Bureau of Aeronautics almost simultaneously with reports that flight surgeons of the War, Navy, and Commerce Departments are planning tests which will show the effect of stratospheric conditions on flyers and passengers.
>
> The incident occurred during an altitude flight by Fighting Squadron Six of the U. S. S. Saratoga.
>
> "One of the oxygen regulators," states the Bureau of Aeronautics report, "began to economize a bit and the pilot became non compus mentis in such short order that he was unable to leave the formation voluntarily before becoming not only a hazard but a menace to the rest.
>
> "As leader of the second section he calmly crawled up and tried to sit in the skipper's lap, then lost distance quite noticeably and finally ended up by flying around in a wide left circle, gradually losing altitude. His wing men saw his shoulders heave as he bravely pulled at the nipple to coax more oxygen into his starving lungs. After descending to 18,000 feet, he regained control of his senses and responded more or less intelligently to the signals of his left wing man, who finally coaxed him back into formation.
>
> "After landing, he could not remember clearly what happened, but about a half hour later, while eating lunch, the memory started coming back. He then reported the following symptoms which may be of interest and value:
>
> 1. Slight twitching of the fingers.
> 2. Twitching of muscles in the wrists.
> 3. Difficulty in controlling the hands.
> 4. Eyesight apparently O. K. but range of vision very short.
> 5. Feeling of annoyance when squadron commander made a turn.
> 6. No apparent discomfort or loss of breath.
> 7. No sense of hearing (had radio but did not respond to repeated calls)."

Barach (41) also mentions the similarity between drunkenness and acute oxygen want and states that the symptoms of drunkenness are increased conspicuously by oxygen want. This would indicate the advisability of not allowing persons who imbibe alcohol to enter atmospheres that may be deficient in oxygen. Barach (41) describes the effects of exposure to low percentages of oxygen as follows:

> Chemical reactions in the body due to oxygen deficiency include a lowered saturation of the arterial blood with oxygen, a decreased content of carbon dioxide, increased urinary acidity, and an increase in nitrogen excretion, especially ammonia, in the urine. Loewy states that these changes may be observed in man at rest at altitudes as low as 2,450 meters, approximately 8,000 feet, and are more pronounced at altitudes of from 10,000 to 12,000 feet.
>
> Several hours of moderate anoxia such as that produced by an altitude of from 10,000 to 12,000 feet, which may result in an arterial oxygen saturation of from 83 to 87 percent, not only produces malaise and other symptoms of oxygen want, but these symptoms are apt to persist for some hours after return to normal oxygen conditions, as pointed out by Peters and Van Slyke, presumably because of cumulative changes that take place in the cells before acclimatization can be accomplished. Recognition of this fact is of importance, since an aviator may be exposed to a reduced oxygen pressure at a certain period in a flight and the effects manifest themselves 3 or 4 hours later when traveling at low altitudes. Furthermore, in some individuals, acclimatization may not be attained for months or years; irritability and various sorts of malaise may be much more marked than at sea level, and prolonged residence at altitudes over 10,000 feet appears frequently to lead to premature cardiac failure. I do not wish to emphasize the more severe symptoms that take place at altitudes of from 12,000 to 24,000 feet in which conspicuous interference with reason, judgment, memory, and control take place along with more pronounced cardiorespiratory symptoms ending in coma and collapse (third stage shown in the table) but to direct attention to the fact that mental impairment such as difficulty in concentrating and increased effort in attempting to concentrate occurs at altitudes of from 10,000 to 12,000 feet to a varying degree depending on the individual. According to Barcroft, the brain is the most vulnerable organ in altitude sickness. Although no opportunity has been had to investigate the pathologic effects of moderate degrees of oxygen want on the human brain, it is of interest to remember that cases of fatal anoxia, chiefly those due to carbon monoxide poisoning, have shown cerebral edema as their outstanding lesion, which may be attributable to the increase in capillary permeability observed experimentally by Landis.
>
> Especially pertinent to our discussion are the results of breathing from 12 to 10 percent oxygen mixtures in a group of patients suffering from psychoneuroses characterized by fatigue,

> neurasthenia, and psychasthema, when compared to normal subjects. Whereas very few of the control subjects showed more than impairment in judgment, memory, and emotional control and physiologic elevation of the pulse and blood pressure, a large percentages of the patients collapsed or showed marked deterioration in mental function. Furthermore, undue fatigue such as that induced by keeping a subject awake the night before the test resulted in responses to low oxygen similar to the patient with neurotic fatigue. Although the degree of oxygen want induced in these studies was definitely greater than that ordinarily employed in transcontinental aviation, the results obtained clearly revealed an increasing inability of the individual suffering from fatigue psychoneurosis to handle oxygen want as compared to the normal person.

These statements of Barach are applicable to mining as well as to aviation and indicate the ill effects that may be expected when men work in mine air deficient in oxygen; these probably increase where temperatures and humidities are abnormally high. The ill effects also may be greater in mines owing to long exposure day after day and year after year to atmospheres only slightly deficient in oxygen than tests of short duration would indicate. Barach (41) intimates such a possibility when he states that "it must be admitted that the short duration of most psychologic tests of oxygen want limits somewhat the knowledge acquired from them." The same criticism doubtless applies to the physiological tests.

According to Flury (42) little or nothing has been known until now of the chronic action of gases in themselves designated as indifferent especially the consequences of breathing them continuously over a period of years; the same is true of methane and carbon dioxide. Moreover, the action of carbon monoxide and hydrogen sulphide, as well as radioactive substances in gases given off by strata with a firedamp content, has not yet been clarified. He states:

> In view of the lack of certitude regarding the chemical bases the connection between mine gases and miners' diseases can be determined only with the greatest caution. On the one hand, the dominant fact is the lack of oxygen and the presence of various gases belonging to the narcotics of the methane series. On the other hand, statistics reveal a whole series of effects on the health of miners. Judgment in the matter is rendered difficult by an extraordinary accumulation of different causes to which must be added the antiphysiological conditions under which heavy work has to be done. There is, nevertheless, no doubt that toxic factors play a part and probably to a much greater extent than has been assumed so far. The lack of oxygen is in itself responsible for diminished resistance in general and exerts in the long run an effect on the various systems. To this is added the varied effects of the gases in question: The influence of carbonic acid, considered as harmless, on respiration, circulation, and metabolism must not be underestimated. Breathing of this gas produces the same effect as physical work. Further, definite data are for the

moment not available except in so far as concerns diseases of the nervous system, the system with the greatest need of oxygen and the most sensitive to poisons. In this field amongst the multiform disorders encountered, the most important is miners' nystagmus. This difficult problem cannot be resolved without taking into consideration the part played by toxicological factors, and in no wise purely on the basis of simple ophthalmological examination. Apart from the well-known causes dealt with in the special literature on the subject and which point to the influence of the air in mines, emphasis must be laid on the fact that amongst the numerous poisons which have been shown experimentally to cause nystagmus, the methane derivatives - hydrocarbons, alcohol, narcotics, etc. - occupy the most important place. Carbon monoxide, lighting gas, benzene, and petroleum also belong to this class. Nystagmus should very probably be considered as a special type of occupational neurosis having as its cause disturbance of coordination. The simplest explanation of its origin is to be sought in a toxic effect exerted on the nervous centers concerned. In the production of complicated disturbance of the reflex apparatus there may be traced the influence of various factors (optic conditions, fatigue, working conditions), the relative importance of which has yet to be determined. It is almost indisputable that the gases in question, perhaps even methane, cause, after exposure lasting for years, a toxic predisposition which favors the outbreak of nystagmus. The probability of this is still greater in regard to other gases, and more especially in regard to the effect of combinations, but absolute proof of this does not so far exist, and to obtain it implies very extensive, thorough, and accurate research which could be best realized by collaboration between the various peoples having at heart the welfare of their workers.

In 1913 Hill and his coworkers (43) called attention to the fact that the partial pressure of oxygen in a mine at a depth of 3,000 feet is considerably higher than at sea level, therefore if the percentage of oxygen is reduced to 17 there need be no lower pressure in the alveolar air of the lungs than at sea level and miners can still live and work without ill effects. A report concerning a place in a mine where a quantity of blackdamp was given off and "a light would not burn 1 foot 6 inches from the floor or in the waste, and yet the men had no fault to find with the atmosphere" is quoted as confirming this, although in this case the air near the floor may have been highly charged with carbon dioxide while the oxygen content of that at the level of the head when standing may have been normal or nearly so. It was claimed that experimental evidence showed that "it is only when the partial pressure of oxygen is lowered very considerably that signs of oxygen want arise." Rees (44), however, states that the percentage of oxygen should never fall below 19 and that the carbon dioxide increase should never exceed 1.25 percent in mines. The Mine Safety Board of the Bureau of Mines (45) in defining pure intake air decided that for health and safety it should contain not less than 20 percent oxygen (dry basis).

The body adapts itself to some extent to lowered percentages of oxygen in the air breathed; that is, the anoxia that would exist without adaptation is greatly diminished, as in persons living at high altitudes, or the tissues may adapt themselves to a lower partial pressure of oxygen. The modern theory (46) is that acclimatization takes place in three ways: (1) By increase in the number of red cells that carry oxygen in the blood; (2) by increase in ventilation of the lungs; and (3) possibly by active secretion of oxygen into the blood by the lungs. Campbell's (46) experiments, however, showed that animals could not be acclimatized and live long at altitudes above 18,000 feet; he found they could live in a concentration of oxygen equal to 12 percent of 1 atmosphere, but not for more than 6 weeks in a concentration equal to 10 percent. Owing to lack of oxygen deterioration sets in, and the animals finally show degeneration of certain organs such as the heart and liver; they recover if exposure to the low concentrations of oxygen is terminated before deterioration has advanced too far. Peters and Van Slyke (22) state that residence at altitudes higher than 10,000 feet, according to general observation, appears frequently to lead to premature cardiac failure. Haldane (19) stated that adaptation requires time, and the time factor must be taken into consideration in judging the effects of oxygen want.

Studies by the Bureau of Mines and the Public Health Service (47) revealed that the neuropathology of dogs exposed to atmospheres depleted of oxygen was similar to that of dogs given equivalent exposure to carbon monoxide.

Carbon Dioxide

Carbon dioxide (CO_2) is a colorless and odorless gas having an acid taste (21). It is the product of complete combustion of carbon or carbonaceous matter in a plentiful supply of air or oxygen (21); it is also a product of the decomposition of organic compounds and of the respiration of men and animals (16). It will not burn or support combustion, and it is heavier than air. Excess CO_2 in mine air usually is associated with oxygen deficiency. Owing to its high specific gravity it usually collects along the floor in low places where it is formed or where it emanates from the rock strata. It is likely to be found in long, unventilated dead ends and in winzes, especially where porous strata and fissured lodes exist, and very few heavily timbered mines are free from this gas, particularly where the mine atmosphere is relatively stagnant (48). Carbon dioxide emanates from the rock strata in underground workings of certain mines, notably in the Cripple Creek (Colo.) and Tintic and Park City (Utah) districts, as well as in numerous other metal-mining regions (16). There have been terrible CO_2 catastrophes in Europe; in July 1930 an outburst of CO_2 in a coal mine in Silesia killed more than 150 persons, of whom some were hurled to death with explosive violence but most were asphyxiated by the very rapid flooding of the workings with CO_2 gas (49).

When CO_2 is breathed in high concentrations it produces a prickling sensation in the mucous membranes of the nose (48). CO_2 fulfills a peculiar

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and important function in human life and is necessary for the growth of vegetation; it is indispensable in the mineral world and is required in all life processes (50). Apparently the carbon dioxide of the blood constitutes the normal stimulus to the respiratory center, whose activity varies with the concentration of carbon dioxide in the blood. When the carbon dioxide pressure is reduced below a certain point in the respiratory center the latter ceases to respond to even the most extreme stimulus of oxygen want (19). In the presence of oxygen a high enough concentration of CO_2 acts as a narcotic and possibly affects the tissues also; when oxygen is lacking CO_2 acts as an asphyxiating gas; it also has a nonspecific acid effect on the skin and mucous membranes (51). The following table, taken from a German pamphlet (50), indicates the physiological effects of exposure to various concentrations of CO_2:

Physiological effects of exposure to various concentrations of CO_2

Experiments Without Apparatus

Carbon dioxide, percent	Location	Reaction
4.4	In exhaled air (16 percent O_2)	
5.5	In the air of pulmonary vesicles	
4-5	In the inhaled air	Deeper breathing due to increased stimulation of the respiratory center.
5-6	do.	Same effect as 4-5 percent (limit of indurance without apparatus).
8	do.	Headache, dizziness.
9.5	do.	Very severe headache, dizziness, preliminary stage of CO_2 narcosis.
10	do.	Unconsciousness, CO_2 narcosis.

Experiments With Apparatus
Without Protective Goggles

20	In the surrounding air	Sensation of heat in skin of tender parts of the body (waist, inner surfaces of arms, scrotum).
40	do.	Severe burning sensation in the eyes.
45	do.	Tears in the eyes.
50	do.	Tears in the eyes and intolerable burning sensation.

Experiments With Animals

60-70	In the surrounding air	Breathing stops after a few minutes.
75-80	do.	Death in the form of apoplexy.

A supersaturation of CO_2 may indicate a lack of oxygen.

In experiments (52) made at the Bureau of Mines experiment station, Pittsburgh, Pa., about 2 percent of carbon dioxide in oxygen produced a slight increase in lung ventilation but no subjective symptoms; 5 percent in oxygen caused a noticeable increase in lung ventilation but no other signs or symptoms; 7.2 percent produced a marked increase in lung ventilation, moderate sweating, and a slight fullness in the head after the mixture had been breathed for 10 minutes; 9 to 10 percent produced about a 300-percent increase in lung ventilation, and the subject complained of frontal headache and was dizzy and sweating at the end of 10 minutes. About 9 percent of carbon dioxide in oxygen was breathed by some of the subjects for as long as 45 minutes, but the breathing was very laborious and dizziness, headache, and sweating were marked. In fact, to have done any work while breathing this mixture would have been extremely difficult. However, the minds of the subjects remained clear. All observations were made with the subjects seated. From these data it was concluded that, although it is possible to breathe 9 to 10 percent of carbon dioxide in oxygen, any percentage above 5 will cause noticeable effects, and between 2 and 2 1/2 percent is all that should be permitted in the inspired air of an oxygen breathing apparatus at any time.

The Underwriters' Laboratories (53) reported the following results of experiments with CO_2 on guinea pigs:

CO_2, percent by volume:	Reaction
5.0-5.4	In 5 minutes caused an increase of approximately 50 percent in rate of breathing in 12 guinea pigs. No difference in reaction between exposures for 5 minutes and for 30 minutes.
10.0-10.40	About same reaction as above. Pigs exposed 1 to 2 hours occasionally rubbed noses.
19.6-20.6	In 1 minute increase of approximately 50 percent in rate of breathing; animals coughed frequently and rubbed noses. At the end of 4 minutes they were losing coordination rapidly; after 5 minutes they were unable to stand; removed to air they partially recovered in 10 minutes but were exhausted next day. After 30 minutes' exposure they were semiconscious; recovered partially on exposure to air for 10 minutes; recovered but were exhausted for 1 day.
29-30	All animals lost coordination within 1 minute, coughed frequently and breathed audibly; all were unable to stand at the end of 3 minutes; recovered partially within 20 minutes after exposure of 5 minutes; after exposure of 30 minutes animals were unconscious; they were exhausted for 2 days but recovered and appeared normal. After exposure for 1 hour, one animal died 24 hours after removal; two others were weak and exhausted 2 days after test. In a 2-hour test 1 animal died at beginning of second hour; two others were unconscious but recovered partially after 1 hour in air; they were weak and exhausted for 2 days but recovered and appeared normal.

According to Flury and Zernik (51) men exposed to 8 to 10 percent (about 144 to 180 mg per liter) of CO_2 quickly lose consciousness and die of cessation of respiration; 20 percent leads in a few seconds to complete paralysis of the important life centers. Action on the skin begins with exposure to 20 percent CO_2. In addition to these general effects, CO_2 also exerts a local action, due to its acid character, as follows (51): Prickling of the skin and reddening of the skin and mucous membrane of the nose and throat as well as of the conjunctiva, increased feeling of warmth, and profuse sweating. Inhalation causes more or less coughing due to irritation and a feeling of warmth in the breast. Individual susceptibility to these local reactions varies; in some persons they appear with exposure to 5 percent; in others, not until a concentration of 10 to 12 percent is reached. Flury and Zernik (51) state that when the feet are held in a layer of CO_2 or pure CO_2 is blown on the skin, immediately there is a feelin of warmth, then itching and stinging, and after a time anesthesia.

According to experiments by Tomaszewski and his coworkers (54) the following changes were noted when 8 percent CO_2 was inhaled for 1 hour:

> The changes may be divided into immediate and late effects. The direct changes produced in the blood of veins and in the respiratory tract consist of increase in the level of carbon dioxide, slight increase in the oxygen capacity, decrease in the saturation of oxyhemoglobin of the respiratory tract, increase in the ventilation of the lungs, increase in the depth and speed of the respiration, increase in the percentage of carbon dioxide in the air vesicles, increase in the percentage of carbon dioxide in the expired air, slight increase in the metabolism, initial quickening and then slowing of the pulse, and tendency to slight increase in the blood pressure. The late changes appearing after several days consist of increase and then decrease of the level of carbon dioxide in the blood of the veins, distinct increase in the oxygen capacity of the blood, better saturation of oxyhemoglobin in the venous blood, increase in the quantity of red blood corpuscles and in the amount of hemoglobin, and marked increase in the capacity of the active lungs.

Knowledge of the fact that respiration is controlled by the central nervous system through the carbon dioxide content of the blood (50) has led to the addition of CO_2 to O_2 in the treatment of cases of gas asphyxia and diseases in which oxygen therapy is indicated. Details of its use in this connection are given in the section dealing with methods of resuscitation and treatment of poisoning by toxic and noxious mine gases.

Carbon Monoxide

Carbon monoxide (CO), frequently but inappropriately called "white damp" (16), is a product of incomplete combustion of carbonaceous materials "White damp" is a term applied by miners to the white mist or steam that under some conditions arises from spontaneously heated coal. Although carbon monoxide is the principal toxic constituent of white damp, the latter term is misleading, as CO is a colorless gas and may be present in mine air from other sources, such as explosions of gas or coal dust, mine fires, and explosives used in blasting. The following analyses from the Bureau of Mines gas laboratory at Pittsburgh, Pa. (55), indicate the approximate amount of CO that may be found in mines under certain conditions:

Type and source:	CO by volume, percent
Mine explosion, immediately after dust explosion (experimental)	8.0
Mine explosion, 1 day after explosion in coal mine	1.0[1]
Mine fire	1.0
Blasting with 40-percent gelatine dynamite, 7 minutes after shooting 100 sticks	1.2
Blasting:	
Products of combustion of black blasting powder	10.8
Products of combustion of 40-percent nitroglycerin dynamite	28.0
Products of combustion of 40-percent ammonia dynamite	5.0

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[1] In some cases, however, 4 percent or more CO has been found in air in mines several days after an explosion.

Pure afterdamp, free of air, may contain as much as 8.6 percent CO, and a large amount of CO is given off by smoky and smoldering fires, so that the gases from a fire may be much more dangerous than the afterdamp of an explosion and from a practical standpoint produce essentially the same effects and require the same precautions (19). Some explosives produce much CO and others little, but in practice all seem to give some; hence, there is always risk of CO poisoning from the gases from blasting where explosives are used unless ventilation is efficient. In fact, CO constitutes a deadly and decidedly dangerous hazard in blasting in mines, as it is generated both by the dynamite fired and by the fuses burned, and its harmful effects may be augmented by the simultaneous presence of other noxious gases such as CO_2, H_2S, or oxides of nitrogen. It is formed particularly in raises, winzes, and development ends after firing. No mine is free of fire hazards, and great loss of life has occurred from the burning of a few cords of timber or even of a box of explosives; in confined spaces these give off enough deadly fumes to kill several hundred men, if they are trapped in a mine in which ventilation is defective (48).

Carbon monoxide exerts its toxic action on man by diminishing the amount of oxygen that can be carried by the arterial blood from the lungs, and it also retards the passage of oxygen from the blood to the tissues. As a result of this double action the tissues of a person who has inhaled CO suffer from anoxia and are forced to work under abnormally low oxygen tension (22). These toxic effects are due to the action of the gas in displacing oxygen from its combination with hemoglobin (red coloring matter) of the blood which normally absorbs oxygen from the air in the lungs. However, the affinity of CO for the blood is about 300 times that of oxygen, and even if only a small amount of the poisonous gas is present in the air breathed into the lungs it will be absorbed by the hemoglobin in preference to oxygen. For a person at rest it has been assumed (56) that 80 percent of the equilibrium values is attained after the following periods:

Concentration of carbon monoxide in air (inclusive)	Percentage blood saturation (80 percent of approximate equilibrium values)	Time, hours
0.02 - 0.03	23 - 30	5 - 6
.04 - .06	36 - 44	4 - 5
.07 - .10	47 - 53	3 - 4
.11 - .15	55 - 60	1 1/2- 3
.16 - .20	61 - 64	1 - 1 1/2
.20 - .30	64 - 68	1/2- 3/4
.30 - .50	68 - 73	[1]20 - 30
.50 - 1.00	73 - 76	[1] 2 - 15

[1] Minutes.

With a given blood saturation, the character and severity of symptoms acquired during exposure to CO depend upon the time required to attain that saturation and the degree of muscular activity, in other words, the extent of oxygen deprivation. The number of symptoms decreases with the rate of saturation; with high concentrations the victim may experience only a few (weakness and dizziness). If a given saturation has been acquired by long exposure to a low concentration, the symptoms and aftereffects are likely to be much more severe than if acquired by a short exposure to a high concentration. Muscular activity increases the number and accentuates the character of the symptoms during exposure; it also brings out latent symptoms after exposure. A person at rest may pass into a state of dizzines and unconsciousness without experiencing any marked previous effects. In general, the predominating symptoms accompanying the various percentages of saturation are as follows:

Percentage of blood saturation:	Symptoms
0 - 10	No symptoms.
10 - 20	Tightness across forehead; possibly slight headache, dilation of cutaneous blood vessels.
20 - 30	Headache; throbbing in temples.
30 - 40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, collapse.
40 - 50	Same as previous item with more possibility of collapse and syncope; increased respiration and pulse.
50 - 60	Syncope, increased respiration and pulse; coma with intermittent convulsions; Cheyne-Stokes's respiration.
60 - 70	Coma with intermittent convulsions; depressed heart action and respiration; possible death.
70 - 80	Weak pulse and slowed respiration; respiratory failure and death.

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In addition to the concentration of CO in the air breathed, length of exposure, rate of respiration, and the presence of other toxic gases, factors governing the physiological reaction are the physical condition and age of the victim. An anemic person or one with damaged respiratory organs would suffer sooner, and young children seem to be somewhat more susceptible to the gas than older subjects. Spilsberry (57) cites the case of a young woman suffering from advanced tuberculosis who committed suicide by inhaling illuminating gas, the fatal blood saturation with CO being only 45 percent. According to Peters and Van Slyke (22) 0.02 percent of CO for a number of hours of exposure may be the maximum concentration permissible for a subject who, because of circulatory or respiratory malfunction, already is separated from anoxia by an abnormally narrow margin.

Nitrogen

Nitrogen, which forms 78.09 percent of normal air, is not a poisonous gas, but it cannot be breathed in the absence of oxygen. A limited amount is held in coal, and nitrogen intrusions from rock strata, while by no means numerous, are not unusual. Accumulation above the normal amount in mine air is due ordinarily to the removal of oxygen from the air by the coal or to oxidation or decomposition of timbers or of some types of rock or ore.

An instance is given of the accidental death of two men in a ripping in a French mine (58) owing to a comparatively small but regular nitrogen blower. The presence of the gas had not been suspected, and no fissure was discernible at the place of the accident. There are also several instances of fatalities from nitrogen intrusions in mines (especially metal mines) of the United States. Nitrogen is not combustible and will not support combustion (16). A German report (33) regarding the effects of nitrogen in a submarine, in which the oxygen supply was cut off unnoticed by the crew due to damage to the vessel and the carbon dioxide content of the air was fixed by alkali cartridge, states that the absence of oxygen is unnoticed by the victim, that he feels better and conjures up pleasant mental images and thoughts accompanied by wish phantasies, and that he then falls suddenly as though stricken by apoplexy and if he is not removed from the dangerous environment, will die in a short time. Apparently the physiological effect of nitrogen is due purely to its action as a diluent of the oxygen of the air.

Oxides of Nitrogen

Oxides of nitrogen are given off in mines when nitroglycerin, blasting gelatin, dynamite, or other high explosives are burned rather than exploded or when the explosion or detonation is defective or incomplete; the concentration also is likely to be high in case of a blown-out shot. Haldane, quoted by Sayers (56), found that when nitroglycerin was exploded the gases of combustion were 63.2 percent carbon dioxide and 31.6 percent nitrogen but that when it was burned in the presence of its own gases the gases of combustion contained 35.9 percent carbon monoxide and 48.2 percent nitric oxide (NO). The latter gas on contact with air is immediately oxidized to peroxide and other oxides of nitrogen with the production of red fumes. Peroxide of nitrogen is probably the most irritating of any of the oxides of nitrogen.

Fumes of oxides of nitrogen are treacherous in that persons subjected to a concentration sufficient to produce only slight irritation of the eyes or respiratory passages at the time of exposure may die within the next day or two from acute inflammation of the lungs and air passages.

A typical instance of the manner in which these fumes affect those unfortunate enough to be exposed to them is described by Irvine, quoted by Hamilton (59), as follows:

> Two white men and three natives were working at the end of a drive, with a crosscut leading off from it about 100 feet from the face. The miners in the crosscut blasted at 3 p. m., before the party in the drive had left and without giving them warning. The latter were imprisoned in the drive for three-quarters of an hour. They felt that they were being gassed and turned on the compressed air, then went to the surface as soon as the smoke cleared. The white men washed, changed, had their evening meal and went to their quarters, as usual. Acute respiratory symptoms came on in both at 10:30 p. m., and when seen by Dr. Macaulay at 11:00 p. m. they were too ill to be removed to the mine hospital, a few hundred yards away. Both eventually recovered under energetic treatment. None of the Negroes reported sick at the time, but the next morning one was found dead, another moribund, and the third so ill that he, too, succumbed.

Investigators (60) at the Banting Institute, Toronto, Canada, claim tha inhalation of small quantities of fumes of oxides of nitrogen along with silica dust greatly increases the speed of formation of siliceous fibrotic nodules - an added reason for the removal of these fumes from mine air befor workers return to the face after blasting.

Sulphur Dioxide

Sulphur dioxide in mine air almost always is an indication of a mine fi (18); however, it is given off sometimes by explosives, especially in the blasting of certain sulphide ores. It is very likely to be present in gob fires in which iron or copper pyrites is burning (16). It may also be given off in mining for sulphur, gypsum, and possibly other substances. Sulphur dioxide is often a component of fogs which settle over cities and adjacent lands.

Sulphur dioxide is a colorless, suffocating, irritating gas with a stro pungent, sulphurous smell. Even relatively small percentages of it are poiso ous. One part in 500 is almost intolerable to breathe and is very irritatin to the eyes and respiratory passages. In moist air sulphur dioxide changes quickly to sulphurous acid, which readily dissolves in water, making sulphuric acid. This happens when it reaches the moist mucous membranes of the nose, mouth, and throat where it produces the well-known caustic effect of sulphuric acid (59).

Ogata and Lehmann, quoted by Hamilton (59), tested human beings and found that irritation from fumes of sulphur dioxide begins with as low a concentration as 0.01 part in 1,000 parts of air, that susceptible people are made ill by 0.03 part, and that animals are killed in 10 minutes by 0.8 part, with dyspnea, cyanosis, convulsions, and catarrhal or croupous inflammation of the respiratory tract. Usually men are able to develop tolerance to relatively high concentrations, apparently without injury.

In an investigation on the effects of sulphur dioxide, Kehoe (61) found that prolonged exposure to approximately 5 to 70 parts per million of sulphur dioxide produced two distinct effects: (1) Irritation of the upper respiratory tract, which is at first acute in character and subsequently subacute or chronic; and (2) systemic symptoms of a mild type such as are associated with any type of increased acid absorption or production in the tissues. He states that the high degree of correlation shown between the systemic symptoms and the frequency of severe exposures indicates that the human organism is highly adaptable to a regular moderate exposure and that it suffers no apparent injury from such exposure. Intense exposures, even though they occur frequently, give no evidence of damage of a serious or permanent type. He found a significantly higher incidence of nasopharyngitis, both chronic and slight, of alteration in the sense of smell and taste, and of increased sensitivity to other irritants. He also found significantly higher incidence of abnormal urinary acidity, tendency to increased fatigue, shortness of breath on exertion, and abnormal reflexes. Kehoe concludes that there is no appreciable danger to health in a frequent or more or less continuous exposure to endurable concentrations and that the effects of exposure to unendurable concentrations are negligible under conditions that allow of quick escape.

Hydrogen Sulphide

Hydrogen sulphide - called "stink damp" from its odor, which resembles that of rotten eggs - is a colorless gas and is usually a product of the decomposition of sulphur compounds. It may also be produced by burning explosives containing sulphur, as considerable amounts are often formed by the use of black blasting powder or the use of dynamite in blasting sulphide ores. Enough hydrogen sulphide has been found in coal and some noncoal mines during normal operations to cause severe eye irritation (16). Dangerous quantities and percentages also are found in the petroleum industry under some conditions and in certain places. In some instances the presence of hydrogen sulphide has been attributed to decomposition of organic debris.

Considerable hydrogen sulphide, which is readily soluble in water, is released from water streams encountered in coal and noncoal mining; it is found sometimes in stagnant water underground, particularly where ventilation currents are absent, and great care must be exercised when accumulations of such waters are disturbed. A gassing accident of this type occurred in one of the mines of the Rand (South Africa) in 1932 (62) while long pilot holes were being drilled in a raise with the intention of holing into an old water-logged area of an adjoining mine. The accumulated water was mine drainage from the surface, seepage through the strata, and drainage from the outcrop and from abandoned sand dumps in the vicinity. It had been standing in the old workings for at least 10 years, and the head of water above the point of holing was 417 feet. The release of the water under pressure - flowing at the rate of approximately 18,000 gallons per hour through the tapped hole - liberated noxious gas, with the result that two Europeans and five natives were fatally gassed. The finding at the subsequent inquest was that the deaths were due to the inhalation of sulphuretted hydrogen gas (62). In a reconstruction of the accident those near the experimental chamber experienced painful smarting of the eyes as soon as the smell of hydrogen sulphide became pronounced, and two men also experienced choking; the concentration of the gas at this point did not exceed 0.009 percent, and the discomforts disappeared immediately when the flow of water was stopped and compressed air turned on the drive. As such a concentration of gas is said (62) to cause symptoms of local irritation only after many hours of exposure, it was decided to investigate what other factor or factors might increase the irritant nature and toxicity of the gas. The principal findings of the inquiry by the Chief Inspector of Mines were:

1. The deaths were due directly or indirectly to inhalation of sulphuretted hydrogen gas.

2. Danger may arise in special circumstances from mine water containing as little as one one-hundredth of the amount of sulphuretted hydrogen necessary to saturate the water.

3. When such water is being tapped measures should be taken to prevent escape of sulphuretted hydrogen into the air, unless the place is sufficiently well ventilated to make such escape harmless.

The following physiological response attends exposure to various concentrations of hydrogen sulphide by volume in air (63):

0.005 to 0.010 percent: Subacute poisoning - slight symptoms such as mild conjunctivitis and respiratory-tract irritation after 1 hour exposure.

0.02 to 0.03 percent: Subacute poisoning - marked conjunctivitis and respiratory-tract irritation after 1 hour exposure.

0.05 to 0.07 percent: Subacute poisoning - dangerous in 1/2 to 1 hour.

0.07 to 0.10 percent: Possibly acute poisoning - rapid unconsciousness, cessation of respiration, and death.

0.10 to 0.20 percent: Acute poisoning - rapid unconsciousness, cessation of respiration, and death in a few minutes.

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Available information on hydrogen sulphide as a health hazard has been summarized by Yant (63) as follows:

1. Hydrogen sulphide occurs more widely, is more toxic, and constitutes a greater industrial health hazard than is generally realized. The principal health hazardous occurrences of the gas are in connection with gypsum mines, sulphur mines, tunnels and caissons in certain localities, sewers and other confined spaces where decomposition of organic matter takes place, blasting of heavy sulphide ores, use of black blasting powder in coal mines, natural gas from certain fields, production and refining of high-sulphur petroleum, its use as a reagent in manufacture of dyes, pigments, and chemicals, and in the rayon industry. The toxicity is comparable to hydrogen cyanide.

2. Two distinct types of poisoning exist - subacute and acute. The former is due to a direct irritating action of the gas on the tissues, producing conjunctivitis and moderate to severe respiratory irritation. Acute poisoning is the result of a toxic action on the nervous system produced by the absorption and presence of hydrogen sulphide in the blood. Unconsciousness and respiratory failure usually occur within a few seconds after exposure, and the important reaction is paralysis of respiration followed in 5 to 10 minutes by cardiac failure. There are no warning symptoms and no pain. Death from acute poisoning is due primarily to asphyxia.

3. There is no indication that abnormal combinations with the hemoglobin are formed or that the poisoning is cumulative. Also, there is no indication of a chronic type of poisoning other than would be expected from repeated irritation of the eyes and respiratory passages. The gas is rapidly oxidized in the blood to form nontoxic compounds, ultimately sulphates.

4. Treatment of the subacute type of poisoning is principally symptomatic. With acute poisoning, rescue must be effected and respiration induced at once by artificial means.

5. Although the characteristic odor of hydrogen sulphide can be detected in dilution of 1 part in 10 million parts of air (a concentration far below that causing deleterious effects after prolonged exposure), fatigue of the sense of smell occurs rapidly, thereby excluding the use of the odor intensity as a warning.

6. Hydrogen sulphide in 100-percent concentrations has been found to have a surface action on the skin (discoloration, red mottling, and erythema). An exposure of the naked arm for an hour, however, did not cause symptoms of action on the nervous system. The entire body of persons has been exposed 30 minutes to 2 percent hydrogen sulphide in air by volume without noticeable effects of any kind. It is concluded that no serious trouble will be experienced by absorption through the skin when respiratory protective devices are worn.

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Prevention and Treatment of Poisoning by Mine Gases

The chief factors in preventing poisoning by the various toxic or noxious gases that may occur in mines or tunnels are:

1. Good ventilation, as this will dilute and carry away the gases (to be discussed in detail in part III).

2. Avoidance of exposure to air known to contain poisonous gases.

3. Use of adequate protective equipment when atmospheres known to contain poisonous gases are to be encountered; keeping calm when it is necessary to enter or be exposed unprotected to atmospheres containing gases; and not hurrying but getting to fresh air as quickly, and with as little exertion, as possible.

4. Using methods of mining or tunnelling, blasting, mucking, etc., which will minimize the occurrence of the gas or its release.

The steps in effective treatment of acute poisoning by poisonous or noxious gases are:

1. The victim should be removed to fresh air as soon as possible.

2. If breathing has stopped, is weak and intermittent, or is present in only occasional gasps, artificial respiration by the Schaefer method should be given persistently until normal breathing is resumed or until after the heart has stopped.

3. Circulation should be aided by rubbing the limbs and keeping the body warm with blankets, hot-water bottles, hot bricks, or other devices, care being taken that these are wrapped or do not come in contact with the body and produce burns. This aids in tiding the body over a period of low vitality. Other stimulants, such as hypodermics of caffein, sodium benzoate, or camphor in oil, should not be administered except by a doctor after he has considered the possibility of overstimulation and consequent collapse.

4. The patient should be kept at rest, lying down in order to avoid any strain on the heart. Later, he should be treated as a convalescent and given plenty of time to rest and recuperate.

5. Aftereffects of poisoning by such gases should be treated symptomatically.

6. It should be emphasized that inhalations, for 20 to 30 minutes, of oxygen or a 5-percent mixture of carbon dioxide in oxygen, if available, will immediately greatly lessen the number and severity of symptoms of carbon monoxide poisoning, as well as decrease the possibility of serious consequences. All industries in which this type of poisoning commonly exists should provide apparatus (inhalers) for the efficient administration of these treatments. The apparatus should be placed at points most convenient for treating carbon monoxide poisoning, and employees should be trained in their use so that resuscitation may be effected immediately.

The value of oxygen treatment is indicated by the experience of Finch and Bruce (64), who believed that oxygen saved their lives on the Kamet expedition. Numbing cold at 25,500 feet threatened disaster until they tried the effects of breathing oxygen. In a few minutes it produced a tingling sensation of warmth, and the next day they climbed 1,800 feet at the rate of 900 feet an hour compared with 330 feet an hour at lower altitudes. Breathing oxygen through the night also entirely cured a porter of bad frostbite, while two other porters who were much less affected and therefore were not given oxygen each lost digits (64).

Chapter 3. Dusts

One of the principal safety, efficiency, and health problems confronting mining men is eradication of dust from mines and mining plants, or so diminishing or diluting it that it will not be a menace to the mine or plant and the workers therein (65).

Metal-mine dust, acting through miners' consumption, lead poisoning, bronchitis, etc., causes perhaps more deaths annually among the approximately 200,000 metal miners in North America than coal dust causes to the approximately 700,000 coal miners through explosions (66).

Insoluble or virtually insoluble dust in underground air generally manifests its harmfulness to the health of miners in some form of lung disease, such as miners' consumption, silicosis, anthracosis, miners' asthma, and possibly pneumonia. Moreover, dusts are largely responsible for much bronchitis, and some soluble dusts are poisonous (66).

The dust of free silica (quartz, flint, chert, etc.) is probably the most harmful of the dusts ordinarily found in underground workings, although physical examinations of underground employees who have worked in dusty air containing coal and shale, as well as in dust from ores of hematite (iron oxide), calcite (limestone), and other essentially nonsiliceous material, show definite lung involvement, indicated by X-ray photographs and by the usual physical or physiologic symptoms, especially shortness of breath (66).

The main sources of dust in metal-mine air in the order of their importance are: Dry drilling of holes for blasting (dry drilling of holes pointed upward, especially at an angle of about 70°, is generally the worst), blasting, shoveling or "mucking" very fine dry material at the working face which is usually poorly ventilated, loading cars from chutes, dumping loaded cars into chutes, and timbering. Dry crushing and other occupations in metal-mine mills are also dangerously dusty. One such mill in Nevada caused so many fatalities that the death certificates of the victims showed the cause of death as a dust disease called by the name of the mill.

Investigation by the Bureau of Mines (67) of 15 representative coal mines in 6 coal-mining States showed the greatest sources of dust to be:

1. Jackhammer drilling produced the greatest concentrations of dust of any of the mine operations, 10 times as much as any of the others, and the other dust-producing operations arranged in decreasing order of concentration were electric drilling, undercutting coal by dry methods, auger drilling by hand, loading coal, undercutting coal with the application of water on cutter bar of mining machines, simultaneous pick mining and loading coal, loading rock, haulage, and, finally, pick mining.

2. The largest total amount of dust was raised by dry undercutting.

3. Undercutting coal without the use of water on the cutter bar raised the greatest concentration of dust of any of the common mine operations; loading coal ranked next and haulage last.

The United States Public Health Service reported (68) the following results of 80 dust determinations - 60 underground and 20 in the breaker - made at an anthracite mine in the United States in 1926:

> The miners and mine laborers, who made up two-thirds of the total force employed in the anthracite mine, were exposed at times to an exceptionally high concentration of dust, namely, almost 1 billion particles per cubic foot of air. The average, however, which takes into account the time spent under different conditions of dustiness, was much less, being 124 million particles per cubic foot of air.
>
> In addition to the miners and their helpers, two other groups of underground workers were exposed to a relatively large amount of dust: (a) The rockworkers and (b) the runners and drivers, who have to enter the miners' workplaces at times when the air is particularly dusty. Considering the time spent in the dusty and relatively nondusty parts of the mine, one may estimate that the average exposure of the runners and drivers was about 36 million particles of dust per cubic foot of air. The remainder of the underground workers were exposed to a relatively small quantity of dust. Aboveground it was found that the men in certain occupations, namely, the coal dumpers, jugmen, and slate pickers, were exposed to nearly as much dust as the coal miners. At the breaker the dust is practically the same as that in the mines.

The rockworkers are the only ones exposed to a dust containing a high percentage of quartz (31 percent). Since the average concentration of dust was 82 million particles per cubic foot of air, it is obvious on the basis of previous experience that these workers have a severe hazard. Small numbers and lack of occupational continuity made specific study of this group impossible.

The principal factors now thought to determine whether exposure to dust will produce lung disease are nature of the dust, particle size, quantity of the dust dispersed in the atmosphere, and length of exposure. Probably numerous other factors, however, exert a more or less definite influence, such as gases, temperature, humidity, posture, rate of work, and nativity (69). Free silica or quartz has been considered the outstanding type of dust in industries with excessive mortality from dust diseases.

The most dangerous dust is said to be that ranging in size from 5 to 0.5 micron (a micron is one one-thousandth millimeter or about one twenty-five-thousandths inch) or smaller. Particles of such size are too small to be seen by the naked eye. Large quantities of larger particles which float in the air cannot be considered harmless, as they tend to clog the protective mechanisms of the respiratory tract and allow maximum quantities of smaller particles to penetrate the lungs where they are likely to do the most damage.

The length of exposure to silica dust required to produce silicosis depends primarily on the individual and the amount and size of the dust particles in the air breathed; however, numerous other factors may exert a definite influence. Data collected by the Bureau of Mines (70) in one study show that first-stage silicotics had worked underground an average of 12.99 years, irrespective of occupation; those in the second stage had worked an average of 15.8 years, irrespective of occupation; and third-stage silicotics had worked an average of 18 years for all occupations. In this particular study the shortest period worked underground was 2 years for first-stage silicotics, and the longest was 40 years for third-stage silicotics. It appears probable that death from dust disease and accompanying complications may result in 2 years or even less from the date of first exposure to heavy concentrations under unfavorable conditions of temperature, humidity, noxious gases, exposure, etc.

As no definite, absolutely reliable standards of allowable dustiness are known, the aim in the prevention of dust disease should be to eliminate dust from the atmosphere breathed by workers, or at least to reduce the dust content to the lowest quantity feasible.

Determination of dust in air breathed by workers is necessary before measures can be taken to prevent dust disease; moreover, it is economically important as evidence of the extent of the dust hazard involved in dusty processes and as a measure of the efficiency of protective devices introduced to mitigate the hazard.

Although none of the dust-determining apparatus available will indicate accurately the exact amount of dust in a given atmosphere, many of them will show the concentration accurately enough to compare the efficiency of methods of dust elimination.

All dusty methods, processes, or practices in mining should be eliminated or at least used with every possible precaution. In metal mines mechanical ventilation, with a definite person or persons in charge, should force moving currents of air to every working place to remove dust, heat, and gases. Water should be used in all drilling, in the sprinkling of ore and rock piles, in the wetting of timbers, manways, and haulageways, and in every place where dust may be found. Where possible all the blasting should be done after a shift; where this cannot be done strict regulations should be enforced as to the wetting of the region of blasting, both before and after firing the shots, as to the removal of all explosive fumes by adequate air currents, and as to the prevention of entrance into a blasted place until all dust, fumes, etc., have been removed. Strict physical examination should be made of underground workers before employment and at intervals of not more than 6 months during employment, and any workers showing unfavorable physical symptoms should be removed promptly from dangerously dusty work.

In coal mines ventilation should be such that air currents will sweep along and past the working faces and places at all times. Water should be piped to all dry faces and used on the cutting chain while undercutting, overcutting, centercutting, or shearing, and the face worker should sprinkle the face within 40 or 50 feet of face (ribs, roof, floor, and coal pile) at least three times daily and should sprinkle (not soak) the top of all loaded cars before they leave the face. Blasting should not be done during the working shift, and under no circumstances should workers return to the working face until all blasting fumes have been removed by the air currents.

Unquestionably, much ill health, including dust disease, of mining people is due to unusual and unnecessary exposure to extremes of heat and cold, complicated by sudden changes from one extreme to the other with little or no protection from attendant or resultant bronchitis, pneumonia, and related diseases. The mining engineer can and should do much to eliminate these hazards. He can do this by giving much more attention in the future to safeguarding workers from undue exposure to dusts, gases, high temperatures, water, and similar discomforts in transporting them into and out of the mines; by giving real attention to air conditioning of mines, especially in and at the working places; and by constructing and maintaining up-to-date wash or change houses.

Prevention and Treatment of Dust Diseases

No cure is yet known for dust diseases, therefore prevention is the only effective remedy. There are two main lines of approach to the problem of dust-disease prevention in industry - the engineering, through control of dust production, and the medical, through selection of workers by examination; success probably depends upon a combination of the two. Methods of prevention will be discussed in part III.

BIBLIOGRAPHY

1. PETERSEN, W. F. The Patient and the Weather, Vol. 1, pt. 1, 1935, 127 pp.
2. RICKARD, T. A. Man and Metals, Vol. 2, 1932, 565 pp.
3. AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEER'S GUIDE, 1936, FOR HEATING, VENTILATING, AIR CONDITIONING, Vol. 14, 1936, 1080 pp.
4. HARRINGTON, D. Metal-Mine Ventilation. Inf. Circ. 6734, Bureau of Mines, 1933, 11 pp.
5. JOSEPH, E. L. The Conditioning of Mine Air With Special Regard to its Purification. Jour. Chem., Met., and Min. Soc. South Africa, vol. 35, June 1935, pp. 360-365.
6. YOUNG, G. J. Physiological Effects of High Temperature and Humidity. Eng. Min. Jour., vol. 88, 1909, pp. 1155-56.
7. BLACK, JOSEPH. Lectures on Chemistry. Ed. Robison, Edinburgh, 1803. Quoted by R. R. Sayers and S. J. Davenport, ref. 10.
8. LAVOISIER, A. L. Hist. Acad. roy. sci., Paris 1777. Quoted by R. R. Sayers and S. J. Davenport, ref. 10.
9. VON PETTENKOFER, MAX. Ueber die Respiration. Ann. Chem. u. Pharm. Supplement-bd. II, 1862-3, pp. 1-70. Quoted by R. R. Sayers and S. J. Davenport, ref. 10.
10. SAYERS, R. R. and DAVENPORT, S. J. Review of Literature on the Physiological Effects of Abnormal Temperatures and Humidities. Reprint 1150 from Public Health Repts., vol. 42, Apr. 8, 1927, pp. 933-996.
11. KITCHIN, J. M. W. An analysis of Modern Ventilation Theories. Heat. and Vent. Mag., vol. 12, 1915, pp. 30-31.
12. SCHROEDER, W. K. Elimination of Organic Products in Air Conditioning. Refrig. Eng., vol. 26, Dec. 1933, pp. 294-300.
13. GRAMENITZKU, M. I., and SIVERTZEV, I. I. The Toxicity of the Air Exhaled by Man. Jour. Physiol., vol. 19, 1935, pp. 1265-1270.
14. YAGLOU, C. P., RILEY, E. C., and COGGINS, D. I. Ventilation Requirements. Heating, Piping, and Air Conditioning, vol. 8, January 1936, pp. 65-75.
15. PIERCE, W. MACL. Odors and Odor Control. Quoted by Yaglou, Riley, and Coggins, ref. 14.
16. FORBES, J. J., and GROVE, G. W. Advanced Mine Rescue Training: Part I. Mine Gases and Methods for their Detection. Miners Circ. 33, Bureau of Mines, 1929, 65 pp.
17. MCKERLIE, J. Air Conditions and the Human Body. Canadian Min. Jour., vol. 56, no. 7, 1935, pp. 272-275.
18. CHANCE, E. M. The Examination and Physiological Action of Pathogenic Mine Atmospheres, With Considerations Governing the Use of Breathing Apparatus. Reprinted from Jour. Franklin Inst., November 1911, 494 pp.
19. HALDANE, J. S. Respiration. New Haven and London, 1922, 427 pp.
20. COWARD, H. F., and JONES, G. W. Limits of Inflammability of Gases and Vapors. Bull. 279, Bureau of Mines, 1931, p. 102.
21. BEARD, J. T. Mine Gases and Ventilation. New York, 1920, 433 pp.

22. PETERS, J. P., and VAN SLYKE, D. D. Quantitative Clinical Chemistry. Baltimore, 1931, pp. 570-652.
23. GLAISTER, J., and LOGAN, D. D. Gas Poisoning in Mining and Other Industries. Edinburgh, 1914, p. 24.
24. LUSSEM. Experimentelle Studien über die Vergiftung durch Kohlenoxyd, Methan und Aethylene. Inaug. Dissert., Berlin, 1886, p. 19. Quoted by Glaister and Logan, Ref. 23.
25. HENDERSON, Y., and HAGGARD, H. W. Noxious Gases and the Principles of Respiration Influencing Their Action. Am. Chem. Soc. Mon. Ser., 1927, 220 pp.
26. HAUTAIN, N. E. Action Physiologique et Pathologique des Grisous Belges. VIIth Internat. Cong. Accidents and Occupational Diseases. Repts., vol. 3, Occupational Diseases, Brussels, 1935, pp. 359-399.
27. EVANS, J. E. The Therapeutic Use of Oxygen. Bull. Med. Soc., County of Erie and Buffalo Acad. Med., vol. 9, Sept. 1932, pp. 14-18.
28. MELLOR, J. W. Modern Inorganic Chemistry, 1918, p. 133.
29. HOWELL, W. H. A Text-Book of Physiology. 9th ed., 1925, pp. 708-716.
30. BERT, PAUL. La Pression barométrique Paris, 1878. Quoted by Howell, ref. 29.
31. EVANS, J. H. The Therapeutic Value of High Concentrations of Oxygen in Pneumonia, Cardiac Decompensation, Asthma, Hay Fever, and Other Diseases. Bull. Med. Soc., County of Erie and Buffalo Acad. Med., vol. 5, June 1923.
32. HILL, LEONARD. Caisson Sickness and the Physiology of Work in Compressed Air. London, 1912, 255 pp.
33. DRAEGER VORTRAEGE (pamphlet). Oxygen. Lübeck, 1934, 4th ed.
34. BARACH, A. L. Oxygen Treatment. Jour. Am. Med. Assoc., vol. 106, no. 9, 1936, p. 725.
35. BEHNKE, A. R., JOHNSON, F. S., POPPEN, J. R., and MOTLEY, E. P. The Effect of Oxygen on Man at Pressures From 1 to 4 Atmospheres. Am. Jour. Physiol., vol. 110, no. 3, 1935, pp. 565-572.
36. JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION. The Responses to Muscular Work. Vol. 96, no. 24, 1931, p. 2041.
37. SCHNEIDER, E. C. A study of Responses to Work on a Bycycle Ergometer. Am. Jour. Physiol., vol. 97, 1931, p. 353. Quoted by Jour. Am. Med. Assoc., ref. 36.
38. SCHNEIDER, E. C. Medical Studies in Aviation: II. Physiologic Observations and Methods. Jour. Am. Med. Assoc., vol. 71, 1918, pp. 1382-1400.
39. HINGSTON, R. W. G. Physiological Problems of Mt. Everest, 1924. British Med. Jour., Dec. 13, 1924.
40. SCIENCE NEWS LETTER. Twitching Fingers Danger Signal at High Altitudes. Vol. 28, no. 760, 1935, p. 281.
41. BARACH, A. L. "Pilot Error" and Oxygen Want: With a Description of a New Oxygen Face Tent. Jour. Am. Med. Assoc., vol. 108, no. 22, 1937, pp. 1868-1872.
42. FLURY, F. Die Wirkungen der aus den Schlagwetteradern Ausströmenden Gase. Same as ref. 26, p. 315-339.
43. HILL, L., FLACK, M., MCINTOSH, J., ROWLANDS, R. A., and WALKER, H. B. The Influence of the Atmosphere on Our Health and Comfort in Confine Places. Smithsonian Miscellaneous Collections, vol. 60, no. 23, 1913, 96 pp.

44. REES, J. P. The Cooling Power of the Air in Dry and Wet Atmospheres and Some Results of Observations Underground. Jour. Chem., Met. and Min. Soc. of South Africa, vol. 36, 1936, pp. 297-301.

45. MINE SAFETY BOARD. Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936. Inf. Circ. 6946, Bureau of Mines, June 1937, 45 pp.

46. NATURE. The 1933 Everest Climbing Expedition and Oxygen. Vol. 134, 1934, pp. 969-970.

47. YANT, W. P., CHORNYAK, J., SCHRENK, H. H., PATTY, F. A., and SAYERS, R. R. Studies in Asphyxia. Public Health Bull. 211, 1934, 61 pp.

48. HARRINGTON, D. Metal-Mine Fires and Ventilation, Inf. Circ. 6678, Bureau of Mines, 1933, 31 pp.

49. HARRINGTON, D. Progress in Metal-Mine Ventilation in 1930. Inf. Circ. 6469, Bureau of Mines, 1931, 17 pp.

50. BANGERT, F. Respiratory Poisons. Draeger Vortraege, Lübeck, Germany, 4th ed., 1934.

51. FLURY, F., and ZERNIK, F. Schädliche Gase. 1931, pp. 218-221.

52. BUREAU OF MINES. Mine Rescue Standards: A Tentative Study. Tech. Paper 334, 1923, 43 pp.

53. UNDERWRITERS' LABORATORIES. Report on Comparative Fire and Explosion Hazards of Common Refrigerants. Misc. Hazards No. 2375, Kinetic Chemicals, Inc., Nov. 13, 1933.

54. JOURNAL AMERICAN MEDICAL ASSOCIATION. Prolonged Respiration of Carbon Dioxide. Vol. 108, no. 12, 1937, p. 1016.

55. SAYERS, R. R., and DAVENPORT, S. J. Review of Carbon Monoxide Poisoning: 1936. Public Health Bull. 195, 1937, 128 pp.

56. SAYERS, R. R. Permissible Limits of Toxic and Noxious Gases in Mine and Tunnel Ventilation. Rept. of Investigations 2734, Bureau of Mines, 1926, 10 pp.

57. BRITISH MEDICAL JOURNAL. Carbon Monoxide Poisoning. July 5, 1930, pp. 17-18.

58. COLLIERY GUARDIAN. A Nitrogen Blower in a Coal Mine. Vol. 153, 1936, p. 346.

59. HAMILTON, ALICE. Industrial Poisons in the United States. New York, 1925, 590 pp.

60. IRON AND COAL TRADES REVIEW. Dust Problems in Coal Mines. Vol. 130, 1935, p. 453.

61. KEHOE, R. A. On the Effects of Prolonged Exposure to Sulphur Dioxide. Jour. Ind. Hygiene, vol. 14, 1932, pp. 159-173.

62. SEGAL, B. Sulphuretted Hydrogen as a Mining Hazard. Jour. Chem., Met. and Min. Soc. of South Africa, vol. 36, 1936, pp. 366-367.

63. YANT, W. P. Hydrogen Sulphide in Industry: Occurrence, Effects, and Treatment. Am. Jour. Public Health, vol. 20, 1930, pp. 598-608.

64. JOURNAL AMERICAN MEDICAL ASSOCIATION. Oxygen in Mountain Climbing. Vol. 97, no. 17, 1931, p. 1236.

65. HARRINGTON, D. The Menace of Dust in Metal Mining. Eng. Min. Jour., vol. 138, 1937, pp. 119-123.

66. ———. Silicosis as Affecting Mining Workmen and Operations. Inf. Circ. 6867, Bureau of Mines, 1936, 14 pp.

67. FORBES, J. J., and EMERY, A. H. Sources of Dust in Coal Mines. Rept. of Investigations 2793, Bureau of Mines, 1927, 17 pp.

68. BRUNDAGE, D. K., and FRASIER, ELIZABETH S. The Health of Workers in the Dusty Trades. III. Exposure to Dust in Coal Mining. Public Health Bull. 208, 1933, pp. 7-19.

69. HARRINGTON, D., and DAVENPORT, S. J. Review of Literature on Effects of Breathing Dusts With Special Reference to Silicosis. Bull. 400, Bureau of Mines, 1937, 305 pp.

70. MERIWETHER, F. V., SAYERS, R. R., and LANZA, A. J. Silicosis and Tuberculosis Among Miners of the Tri-State District of Oklahoma, Kansas, and Missouri. II. For the Year Ended June 30, 1929. Tech. Paper 552, Bureau of Mines, 1933, 28 pp.

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